FUEL AND LITTER CHARACTERISTICS IN FIRE-EXCLUDED AND RESTORED NORTHERN MISSISSIPPI OAK-HICKORY WOODLANDS

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Abstract—Oak-hickory communities are a widespread component of the landscape in the southeastern United States, often providing critical habitat and containing high plant species richness. With changing land use and fire exclusion, however, species composition has shifted in many areas to off-site species that are more fire-sensitive. These fire-sensitive species often create a closed-canopy structure (termed "mesophication") and composition that changes fire dynamics and complicates restoration efforts. One important, but understudied, aspect of mesophication is the potential change in fuelbed characteristics that affect fire behavior and future regeneration environments. This study combines fire exclusion controls with canopy thinning/prescribed burning treatments at two oak-hickory woodland sites in northwest Mississippi in order to examine how fuels change with mesophication and restoration efforts. We sampled downed woody fuels and duff depths using planar intercepts and also collected tree litter in destructively sampled quadrats. Most fuels characteristics (1-, 10-, 1000-hour woody fuel loading and fuelbed depth) did not differ between controls and treatments, however at one site the treatment had significantly lower duff depth and higher 100-hour fuel loading. In both restoration treatments, litter composition shifted towards a greater composition of flammable red oak species. Overall, restoration treatments at these sites are resulting in the functional restoration of flammable oak-hickory woodlands.

INTRODUCTION

Fire-maintained woodlands were an important and extensive component of the landscape throughout the eastern U.S. prior to European settlement (Stambaugh and others 2015). The vast majority of these ecosystems have experienced significant declines and degradation across most of their extent. In pyrogenic oak-hickory (*Quercus-Carya*) dominated woodlands in the southeastern U.S. a major source of degradation is fire exclusion, which allows the invasion and establishment of fire-sensitive species (Nowacki and Abrams 2008). These fire-sensitive species can in turn reduce the flammability of the community through a positive feedback process termed "mesophication" due to the lower flammability litter, faster decay rates of litter and woody debris, and alteration of microclimates to promote moister forest floor conditions (Nowacki and Abrams 2008). In addition, Kreye and others (2013) found that fire-sensitive species have litter that absorbs more moisture and dries at a significantly slower rate than fire-tolerant species, both of which would result in dampened ignition and fire spread rates.

Restoration treatments in the region generally target the removal of selected fire-sensitive species, however the effectiveness of these treatments on fuels and flammability have not been well-studied. As efforts to restore fire-maintained woodlands proceed it is critical to develop an understanding of how restoration changes community flammability (Stambaugh and others 2015). Our objectives were to examine the effects of restoration (selective cutting and prescribed fire) on site flammability by examining surface fuels and litter species composition in a southeastern oak-hickory woodland.

METHODS

The study sites are located in mature (containing dominant trees older than 100 years) upland oak-hickory woodlands at the Strawberry Plains Audubon Center near Holly Springs, Mississippi. Dominant tree species include southern red oak (*Quercus falcata*), scarlet oak (*Q. coccinea*), black oak (*Q. velutina*), blackjack oak (*Q. marilandica*), white oak (*Q. alba*), post oak (*Q. stellata*), mockernut hickory (*Carya tomentosa*), sand hickory (*C. pallida*), winged elm (*Ulmus alata*), sweetgum (*Liquidambar styraciflua*), and American sycamore (*Platanus occidentalis*). Other species were present on the sites but they did not contribute significantly to the litter composition.

Paired, adjacent control and treatment plots (each plot ~ 2.5 acres) were established at two sites approximately 2 miles apart (Wildflower and Sharecropper [fig. 1]).

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Figure 1—Study site photos of two north Mississippi oak-hickory woodland sites, Wildflower (left) and Sharecropper (right), during 2014 litter collection. Photo credit: Rochelle Bailey.

Treatment plots were selectively thinned to remove targeted fire-sensitive tree species and to reduce remaining dominant species canopy cover by ~10 percent to approximate pre-settlement conditions (Brewer 2001). Thinning was mostly accomplished by girdling or herbicide application, but some trees were also cut and felled. The Wildflower treatment plot has had five prescribed fires since 2005 and the Sharecropper treatment has had three prescribed fires since 2008; at both sites the burns generally occurred in spring/summer. The Wildflower site has experienced little anthropogenic disturbance, although it has experienced fire exclusion since ~ early 1900's. Areas around the Sharecropper site were farmed historically and subsequently grazed by cattle until ~ early 2000's (Personal communication. Chad Pope. 2014. Staff Ecologist, Strawberry Plains Audubon Center).

Litter was collected in ten 3.3×3.3 foot frames randomly distributed throughout each plot. Four samples per plot were then randomly selected in the lab and sorted to separate out non-leaf material and all leaves that were identifiable to the species level. Due to the similarity of their leaves, decaying scarlet and black oak could not be accurately separated and were therefore lumped into a single category called scarlet oak, which appeared to be the majority of leaves. Leaves that were too damaged to confidently identify were also included in an "unidentifiable" category to ensure the full litterbed was represented. Sorted leaves were then oven-dried at 140° F until no further weight loss was observed.

Downed woody fuels were measured in seven planar intercepts (extending in random directions from systematically distributed start points) per site. Planar intercepts followed the methods in Brown (1974), with 1-hr (diameter <0.25 inches) and 10-hr (0.25 to 1 inch) woody fuels sampled along the first 6 feet, 100-hr (1 to 3 inches) fuels sampled along the first 12 feet , and 1,000-hr fuels (> 3 inches) sampled along the entire 50 foot transect. Fuels within the 1,000-hr category were divided into sound and rotten categories according to Brown (1974). Fuelbed depth was measured three times at the highest point per one foot section along the first three feet of the transect. Duff depth was measured at two points one foot and three feet from the start of the transect.

Percent similarity between plot litter species composition was measured using the Proportional Similarity Index (calculated by summing the lowest percentage for each species in the two plots being compared) on plot averages of dry litter weight percent per species. Site differences in fuels (1-hr, 10-hr, 100-hr, 1,000-hr, and duff) were analyzed using ANOVA or the non-parametric Kruskal-Wallis method when assumptions of normality and equal variance were not met. When differences were detected, post-hoc Tukey-Kramer or Kruskal-Wallis z-tests (non-parametric) were used to isolate pair-wise differences. Analyses were run in NCSS or R statistical software and evaluated using $\alpha = 0.05$.

RESULTS

There were clear changes in litter species composition after the restoration treatments (fig. 2). The Wildflower control (fig. 2A) and treatment (fig. 2C) were 39 percent similar in the relative contribution of different species to leaf litter. The Sharecropper control (fig. 2B) and treatment (fig. 2D) were slightly more similar (45 percent similarity). The two controls were 58 percent similar, whereas the two restoration treatments were 33 percent similar. At both sites there was an increase in the contribution of red oaks (mainly southern red oak, scarlet oak, and blackjack oak) to the leaf litter of the restoration treatment sites and a corresponding decrease in the contribution of white oaks (post oak and white oak). At Sharecropper (fig. 2, B and D) the contribution of hickory remained similar, at 6.9 and 7.6 percent for the control and treatment respectively.

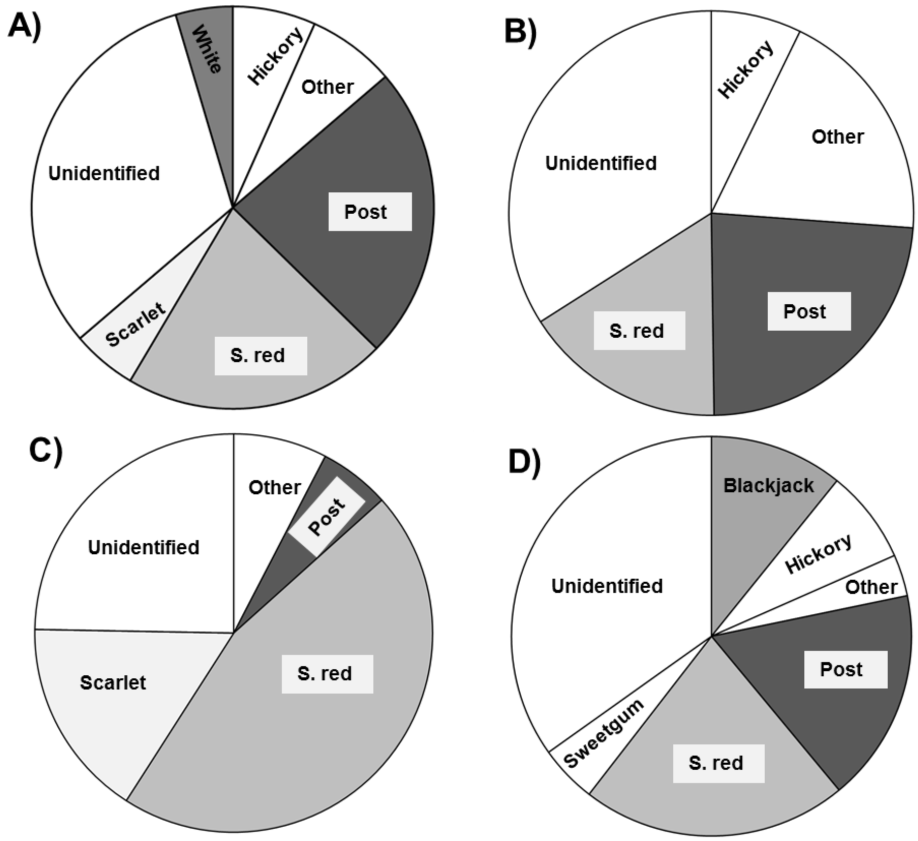

Figure 2—Average percent composition of leaf litter at two north Mississippi oak-hickory woodland sites, Wildflower (left, A and C) and Sharecropper (right, B and D). Control plots are shown in the top row, with corresponding treatment plots on the bottom row. Species that individually contributed less than 5% by weight to litter have been grouped and labeled as "Other" for clarity.

At Wildflower, however, the contribution of hickory decreased from 6.7 to 2.2 percent in the control and treatment.

The richness of identified species contributing to the litter decreased in the treatments at both sites. At Wildflower, the control had identifiable leaves of 14 different species, while the restoration treatment had only 8 identifiable species. The Sharecropper site control had 16 species contributing to the litter composition, while the restoration treatment had only 12 species.

Woody fuels did not generally differ between sites (table 1), however there were significant differences detected for duff depth ($p=0.014$) and 100-hr fuels ($p<0.0001$). Wildflower, but not Sharecropper, had significantly lower duff depth (fig. 3A) in the treatment (0.19 inches) than in the control (1.05 inches). Wildflower, but not Sharecropper, also had lower 100-hr fuel loading (fig. 3B) in the control (0.00 tons/acre) than in the treatment (4.84 tons/acre).

DISCUSSION

In general, the restoration treatments on these sites resulted in greater dominance of the leaf litter bed by flammable red oak species (fig. 2). Southern red oak, blackjack oak, and scarlet oak are known to be highly flammable (Varner and others 2015), with characteristically rapid drying (Kreye and others 2013) followed by high intensity flaming combustion of their curled litter. These oaks also accrue protective bark at young ages, enabling survival in frequent surface fires (Jackson and others 1999).

Classical mesophytic species such as red maple did not comprise a substantial portion of the litter bed even in control plots, generally contributing less than 10 percent of the litter bed combined. Many of these species are also absent from the litter of the treatment plots, although this does not necessarily indicate that those species have been extirpated from the plot. These species have likely only been reduced to a low enough density that they were not detectable in the leaf litter of the treatment plots. Aside from red maple, species in the "other" category included American beech, winged elm, American sycamore, and sweetgum. These species

Table 1—Fuels averages from planar intercepts at two north Mississippi oak-hickory woodland sites, Wildflower and Sharecropper. Means are given with standard deviation, with p-values from Kruskal-Wallis ANOVA (tests significant at an α=0.05 level indicated by an asterisk)

	Wildflower control	Wildflower treatment	Sharecropper control	Sharecropper treatment	P-value
Duff depth (in)	1.05 (0.63)	0.19 (0.14)	0.66 (0.31)	0.59 (0.45)	0.014 *
Fuelbed depth	2.60 (0.56)	2.80 (1.27)	2.60 (0.43)	3.48 (2.93)	0.050
1-hr (tons/ac)	0.20 (0.08)	0.16 (0.05)	0.12 (0.03)	0.16 (0.11)	0.310
10-hr	0.74 (0.55)	0.96 (0.67)	0.39 (0.49)	1.57 (1.60)	0.199
100-hr	0.00 (0.00)	4.84 (2.42)	0.69 (1.18)	3.82 (3.11)	<0.001 *
1000-hr sound	0.60 (1.58)	1.60 (1.40)	0.69 (1.30)	0.45 (0.89)	0.133
1000-hr rotten	0.18 (0.48)	5.11 (6.54)	0.25 (0.66)	2.11 (4.28)	0.205

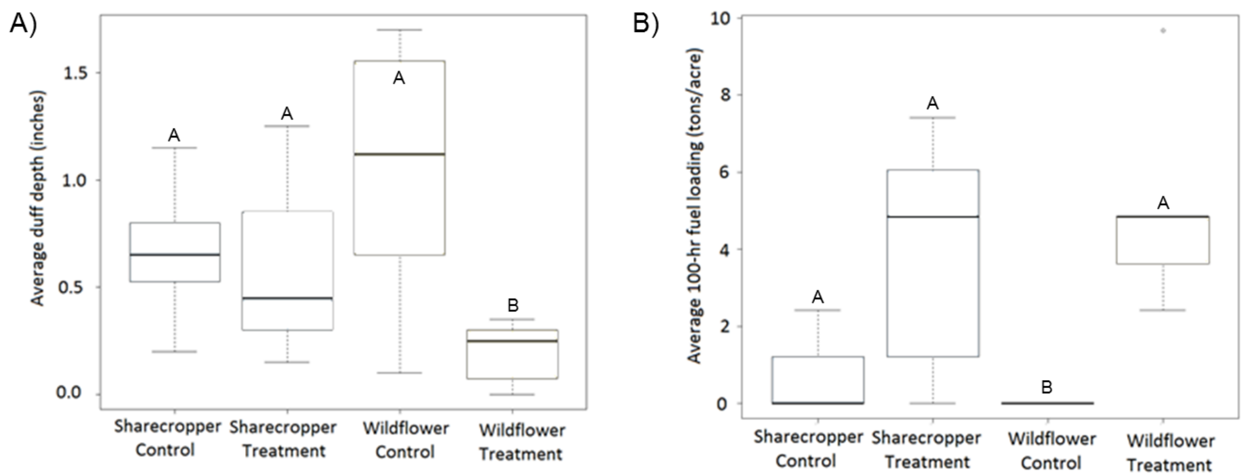

Figure 3—Boxplots highlighting the significant differences (see Table 1) in duff depth (A) and 100-hr fuel loading (B) at two north Mississippi oak-hickory woodland sties. Significant differences between plots (Kruskal-Wallis z-test) are indicated by different letters.

are generally characterized by slow drying rates and typically poor combustion (Kreye and others 2013, Mola and others 2014). These species also accrue protective bark slowly (Jackson and others 1999), preventing their survival and persistence where fires are frequent, though adults of these species typically have bark thick enough to survive prescribed fires.

While it might be expected that the restoration treatments would have lower woody fuels loading due to consumption in prescribed fires, the restoration methods likely resulted in an ongoing influx of woody material due to girdling. This slow attrition likely resulted in the significant increase in 100-hr fuels in the treatment plot at Wildflower (fig. 3B). Sharecropper appeared to have a similar pattern; however the variation is too high for the differences to be considered significant. As killed trees fall and recruit to the surface, likely increases in fire severity will occur. Regardless, the current trend appears to be that girdling increases the amount of 100-hr fuels on the ground and thus would increase community flammability.

The protracted fire-free period prior to restoration resulted in accumulation of forest floor litter and duff. Wildflower has a significantly thinner duff in the restoration treatment while no differences were detected at Sharecropper (fig. 3A). These differences in duff depth could be a result of site history and location. The control at Wildflower has likely experienced a longer period of disturbance exclusion than Sharecropper and thus might be expected to have developed a thicker and more continuous duff layer, which is compounded by the fact that Sharecropper is a generally steeper site.

The components examined in this study are only a small part of the broader picture of community flammability. Fuel moisture changes caused by canopy opening, changes in herbaceous understory biomass and cover, and potential effects of varying leaf litter mixtures are other key factors that need to be examined in order to get a better picture of changing fire potential with restoration of this woodland. As restoration treatments continue, it is important to consider and evaluate whether these treatments are actually restoring functional site flammability to desired levels. The increases in dominance of litter by high flammability red oaks and increases in 100hr fuels restoration treatments found at these sites are likely increasing the flammability of these oak-hickory woodlands as a direct result of the restoration treatments implemented. As litter contributions shift over time, these species may facilitate surface fires at frequencies previously recorded across the region and maintain species dependent on open woodlands (Stambaugh and others 2015).

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